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A Task Force Report has been prepared to provide a compilation of the existing technical and scientific data related to the issues raised by wastewater disinfection. The report is divided into four main parts--Summary, Conclusions and Recommendations; Public Health Effects and Considerations; Toxic Effects on the Aquatic Environment; and Disinfection Process Alternatives. Also included in the report is a summary of the Agency's ongoing research and development program in the area of wastewater disinfection and alternate means of disinfection.

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DISINFECTION OF WASTEWATER

TASK FORCE REPORT

U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C. 20460

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TASK FORCE MEMBERS

Alan Hais (Chairman)	- Office of Water and Hazardous Materials
John Stamberg (former Chairman)	
Joseph Cotruvo	- Office of Planning and Managment
Lehn Potter	- Office of Water and Harardous Materials
William Sonnet	- Office of Enforcement
Cecil Chambers	- Office of Research and Development
James Basilico	- Office of Research and Development
William Brungs	- Office of Research and Development
Edward Opatken	- Office of Research and Development
Edward Brooks	- Office of Water and Harardous Materials
Pamela Quinn	- Office of General Counsel
Lyndell Harrington	- Region VII

ACKNOWLEDGEMENTS

The following personnel from the Office of Research and Development contributed to the preparation of the Task Force Report:

Office of Environmental Engineering

Municipal Pollution Control Division

William A. Rosenkranz

James V. Basilico

Edward J. Opatken

NERC, Cincinnati

Advanced Waste Treatment Research Laboratory

Cecil Chambers

Office of Environmental Science

Ecological Processes and Effects Division

Frank G. Wilkes

Water Supply Research Division

Hend Gorchev

NERC, Corvallis

National Water Quality Laboratory, Duluth, Minnesota

William A. Brungs

William P. Davis

National Marine Water Quality Laboratory, Naragansett, Rhode Island

Victor Cabelli

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SECTION I - SUMMARY

Task Force Origin

An intra-agency Task Force was formed in early 1974 to develop the necessary background information for consideration of agency policy on wastewater disinfection requirements and the use of chlorine. During that time the major consideration of the Task Force was the need for universal year-round disinfection and whether the present secondary treatment regulation should be modified to allow flexibility. Since the input to the final report would originate from ORD personnel, ORD was requested by the Deputy Assistant Administrator for Water Programs, OWPO, on December 3, 1974, to assume the responsibility of completing the Task Force report.

Objective of the Task Force

The main objective of the ORD Disinfection Policy Task Force was to provide information in the form of guidance on public health and water quality requirements, the potential toxic effects of chlorination to both the aquatic and human environments and alternate methods for disinfection. More specifically the Task Force objective was to prepare a summary report for use by the Office of Water Programs Operations in dealing with the chlorine issue and in planning disinfection policy regarding the need to revise the disinfection requirements to meet secondary treatment regulations.

Summary

The members of the Task Force have objectively reviewed all aspects of wastewater disinfection with regards to public health and water quality requirements, toxic effects and availability of alternate processes. As a result of this review the Task Force findings may be highlighted as follows:

1. Disinfection of sewage effluents does provide an effective means of reducing to a safe level the hazards of infectious disease in receiving waters. The requirements for disinfection are based on public health considerations and have greatly reduced waterborne disease outbreaks. Under certain circumstances and locations such as high dilution and die off, seasonal recreation, and no downstream reuse potential, the benefits of disinfection for protection of public health are minimized and may not be needed. The reaction by-products of certain disinfectants have been identified with potential health hazards; these properties must be considered when disinfection is practiced.

2. The toxic effects of total residual chlorine on fresh water organisms have been further confirmed at very low concentrations. Dechlorination greatly reduces or eliminates the toxicity caused by residual chlorine; its effect on reducing chlorinated organics is not known. Brominated effluent may be as toxic as chlorinated effluent, but its toxicity is reduced to no-effect concentrations in a much shorter period of time than chlorinated effluent (minutes instead of hours). No acute adverse effects from ozonated effluents were observed. There is limited information on the effects of chlorine residuals on marine and estuarine life.

3. There are satisfactory alternate disinfection processes that could be substituted in place of chlorination. Results have shown that dechlorination is effective in reducing the toxic effects associated with residual combined chlorine. Ozone is an effective disinfectant when applied to tertiary treated effluents. Bromine chloride is an effective disinfectant on secondary effluent with less toxic effects than chlorine to aquatic life. Recent improvements in ultraviolet light disinfection equipment design gives this process improved potential for wastewater application.

SECTION II CONCLUSIONS and RECOMMENDATIONS

Conclusions

The Task Force believes that the disinfection of wastewater for pathogen destruction is of obvious public health importance since these organisms, if not destroyed, could be transmitted to man through sewage contamination of water for drinking, food processing, irrigation, shellfish culture or recreational purposes. However the application of disinfection regulations should be periodically updated to take advantage of new findings and technology in order that EPA make prudent and efficient use of our nation's resources in administering the secondary treatment regulations. There are a number of conclusions that can be made from this Task Force report that would help to support new policy decisions on disinfection. These conclusions are listed in the discussion that follows.

1. Disinfection of wastewaters is needed for protecting the public health when the receiving water is used for water supply, recreation, irrigation, etc. Although disinfection of drinking water is an essential step for protecting public health, the disinfection of wastewaters should more appropriately be decided on a case-by-case basis taking into consideration the effects of wastewater disposal practice on the different waster uses.

2. Chlorine is currently the predominant wastewater disinfectant and it is essentially the exclusive disinfectant if one includes its counterpart, sodium hypochlorite. Disinfection of secondary effluents with chlorine can reliably meet the present bacteriological standards for secondary treatment.

3. Disinfection of water and wastewater with chlorine can result in formation of halogenated organic compounds that are potentially toxic to man.

4. Disinfection of wastewaters with chlorine can result in a residual chlorine level that is toxic to fish. Although additional research needs to be conducted, available data indicate that chlorine concentrations below 0.01 mg/l and 0.002 mg/l have no adverse effects on warm water and cold water fish respectively.

   Available data, though limited, indicated that chlorine at concentrations in excess of 0.01 mg/l poses a serious hazard to marine and estuarine life. Additional study of many organism types under a wide variety of environmental conditions is needed to establish definitive criteria for chlorine.

5. Dechlorination with suflur dioxide is practiced at full scale facilities where chlorine residuals must be eliminated. Although no criteria for dechlorination chemicals can be proposed at this time, no adverse acute effects were observed on fish following dechlorination with sulfur dioxide.

6. Dechlorination with carbon is feasible but costly. Additional research is required to provide accurate cost and operating data. Health effects research is also required to establish if carbon is effective for removing the potentially toxic compounds formed during chlorination.

7. Ozone is finding acceptance at a few full scale plants. As of now, secondary effluents will require filtration as a teriary treatment stage to consistently meet the fecal coliform standard (200 fecal coliforms/100 ml) with ozonation. No criteria can be estimated as yet for ozone although data on fish toxicity indicate that the effluent disinfected with ozone is less toxic than with chlorinated effluent.

8. Bromine chloride is the newest disinfectant in the field of alternates. It is an effective disinfectant for secondary effluents and it is less toxic to aquatic life than chlorine. Health effects are unknown.

9. Although ultraviolet light has not been widely used to disinfect wastewater, there is limited information that indicates it may become a potentially desirable alternative. It is the only physical process whereas all the other disinfectants are chemical processes. On-going research will provide answers as to its applicability to adequately disinfect wastewater.

Recommendations

The Task Force feels that when disinfection standards are set, the interests of human health have to be considered paramount. As with all environmental decisions, we may still have to consider a trade-off of values in which it may be necessary to compromise the optimum natural ecology of limited stretches of receiving waters to the greater interest of protecting human life.

The basis for establishment of disinfection standards has been subject to controversy for many years. The summary of the states' disinfection regulations show many different requirements and further compounds the issue of uniform secondary treatment standards. In view of the many factors presented in this report and considered by the Task Force, the following recommendations are made:

1. Disinfection of wastewaters is needed to protect public health where the receiving waters are used for purposes such as downstream water supply, recreation, irrigation, shellfish harvesting, etc.

2. Modify the present standards and regulations for disinfection in order to allow flexibility in regard to year-round requirements. Also where it can be demonstrated that the protection public health is not involved additional flexibility should be allowed in the consideration of across the broad disinfection. Criteria should be developed for these areas.

3. The exclusive use of chlorine for disinfection should not be continued where protection of aquatic life is of primary consideration. However when chlorine is used, the residual combined chlorine in the receiving waters should not exceed the recommended levels. Use of alternate processes should be encouraged by the Agency through a vigorous promotion of the new alternates.

4. The use of alternate disinfectants should be further pursued because of recent findings of the potentially hazardous halogenated organics in drinking water.

SECTION III - INTRODUCTION

BACKGROUND

Prior to the enactment of P.L. 92-500, domestic wastewater disinfection practice was, for the most part, controlled locally by the States. Disinfection requirements were based on water quality standards and/or specific disinfection criteria which applied to the discharge of wastewater. Implementation of disinfection policy through the States generally resulted in flexible requirements which were related to the protection of public health. Seasonal disinfection of wastewater was practiced in many States, while no disinfection was required for certain wastewaters where such a discharge did not endanger public health. The present regulations require continuous disinfection of all domestic wastewater on the basis that disinfection is an "important element of secondary treatment which is necessary for protection of public health." The selection of the disinfection process to meet the fecal coliform limitations was limited to chlorination since it was the only wastewater disinfection process available for widespread use by municipal wastewater treatment plants. The net result was EPA policy in conjunction with available disinfection technology encouraged the use of chlorination.

Before the enactment of P.L. 92-500, little consideration was given to possible effects that indiscriminate use of chlorine might have on fish and other aquatic organisms. These adverse effects were clearly brought out in a memorandum "Problems with Chlorination of Effluents", August 24, 1970, to the Federal Water Quality Administration Commissioner from the Nation Water Quality Laboratory Duluth, Minnesota. However the cost, reliability and potential impact of the alternative disinfectants were questionable at that time to adopt a significant change in FWQA's position with respect to disinfection techniques. Also at that time, the formation of halogenated organics and other reaction by-products was recognized but the extent and magnitude was not quantitatively defined. Only recently, through improvements in analytical techniques and the public concern for drinking water quality, has the potential health hazard of halogenated organics been brought out.

An R&D program was approved for implementation to develop disinfection alternatives and the necessary bioassay support work. Consistent with the state-of-the-art at that time, emphasis was put on further developing the dechlorination and ozonation processes as the likely candidates that could supplement chlorination.

Top priority was given to the need for developing new alternatives to chlorination. The grant with the City of Wyoming, Michigan, is the major part of this program. Although the project is only 50% completed it has produced significant results and has shown that dechlorination, ozonation and bromine chloride are effective processes with lesser toxic effects than chlorine. Recent improvements in UV equipment design gives this process greater potential to wastewater applications, especially for small plants.

Additional bioassay information on chlorine toxicity and new bioassay data on dechlorination, ozone and bromine chloride have been obtained. Some definitive water quality criteria for these disinfectants are being developed but additional work is needed.

A national survey is being conducted in order to determine the formation of halogenated organics through disinfection of water supplies. Samples will be collected from some 80 water supply systems and halogenated organics determined before and after chlorination.

Research is in progress to provide the data base required for the development of recreational water quality criteria. Epidemiological-microbiological studies are being conducted at several bathing beaches in order to correlate incidence of diseases among swimmers to some microbial indicators of pollution. The currently accepted fecal limit for recreational waters will be re-evaluated in light of new findings. This, in turn, will decide the extent of wastewater disinfection if recreational waters are to be safe for the public.

The following sections discuss the present status and highlights the research findings on public health effects, the effects of disinfectants on aquatic life, and alternative disinfection processes.

SECTION IV - PUBLIC HEALTH EFFECTS

Rationale for Disinfection

A variety of infectious microorganisms are found in the feces of active cases or carriers and, hence, in municipal wastewaters containing the fecal wastes from such individuals. Included are salmonellae, shigellae, enteropathogenic Escherichia coli, Pseudomonas aeruginosa and a variety of enteric viruses, including hepatitis (1). Furthermore, outbreaks of gastroenteritis, typhoid, shigellosis, salmonellosis, ear infections due to Pseudomonas aeruginosa, and infectious hepatitis have been reported among individuals drinking or swimming in sewage contaminated waters or consuming raw molluscan shellfish harvested therefrom (2-7).

The range and densities of pathogens in municipal wastewater effluents are, of course, dependent on the number of active cases and carriers in the discharging population at any given time. However, even if it were practical to monitor raw sewage for the variety of potential pathogens therein, good public health practice requires the assumption of their presence in sufficient numbers to produce a reasonable probability of disease even when small quantities of sewage are injested. The obvious solution to this problem is to reduce the pathogen density in the target waters receiving municipal wastewaters so that the probability of "contact" with an infective dose of a particular pathogen is reduced below some acceptable limit. From experience and judgment, this limit has been associated with a median fecal coliform density of 14 fecal coliforms or 70 total coliforms per 100 ml in shellfish growing water (8,9). From a limited quantity of epidemiological data, it has been associated with 200 fecal coliforms per 100 ml in primary contact recreational waters (10,11). For raw surface waters to be used as water supply sources and receiving conventional treatment, the National Academy of Sciences recommendation is to limit the geometric means of fecal coliform concentrations to 2,000 per 100 ml (12).

The above water quality criteria can be achieved by the physical removal or chemical destruction (disinfection) of the pathogens and indicator microorganisms at the source of their dilution together with natural die-away in transit to the target. Primary and secondary treatment systems were not designed for nor are they particularly effective in reducing microbial densities in wastewaters. Their effectiveness as reported in the literature varies with the organisms being studied, the type of treatment and the operative conditions during the study (13-15). In general, the combined effect of primary and secondary treatment does not reduce pathogenic bacteria and viruses or indicator bacteria more than 90 percent. However, the effectiveness of disinfection is enchanced by the removal of solids and nutrients during treatment.

Benefits of Disinfection

Chemical disinfection of wastewaters using chlorine is an effective means of reducing the density of pathogenic and indicator bacteria provided that solids and interfering materials are reduced by preliminary treatment, residual chlorine levels are maintained at 3-5 mg/liter and the contact time is sufficiently long. Reductions of 99.9 to 99 percent have been reported with salmonellae and coliform bacteria (16,17). Velz (18) notes that is feasible to achieve and maintain a residual coliform bacterial density of 500/100 ml, representing an efficiency of 99.995 percent. Bromine chloride (19) and ozone (20) are reported to be as or more effective than chlorine.

In general, enteroviruses such as poliovirus, coxsackie, etc., appear to be more resistant than bacteria to chemical disinfectants such as chorine, although the sensitivity varies considerably by species, type, and even strain. Hepatitis virus is thought to be the most resistant of all. Kelly and Sanderson (21) found a greater than 99 percent kill of polio virus at residual chlorine levels at 0.1 to 0.3 mg/l with a 2 minute contact time. Clarke, et al (22) reported a 99 percent kill of adenovirus with 0.1 mg/l HOCl in 12 seconds. At the same concentration of hypochlorous acid, a 99 percent kill of poliovirus I and coxsackie virus A2 were attained in 8 minutes and 40 minutes respectively. Shuval et al (23) in their study of the effects fo chlorination on trickling filter effluents, reported that residual chlorine at 3 mg/l with a 30 minute contact time killed 99 percent of Echo 9 virus and 50 percent of poliovirus I. Bromine chloride was reported to be more effective than chlorine for the destruction of poliovirus II (19).

The introduction of chlorine in the early 1900's for the disinfection of water supplies resulted in a dramatic decline in waterborne disease outbreaks. Major cholera and typhoid epidemics attributable to contaminated water supplies are a thing of the past. Craun and McCabe noted that from 1951 to 1970 about fourteen waterborne disease outbreaks occured each year in the United States (24). However, for 1971 and 1972 the rate has increased to an average of 24 outbreaks per year. Most common causes of these outbreaks are: lack of disinfection of groundwater, breakdown of chlorination equipment, cross-connections (25).

In both the shigella (3) and salmonella (2) outbreaks of swimming assocated illness, there appears to have been a breakdown in wastewater treatment. In addition, a number of the reported outbreaks of shellfish associated infectious hepatitis appear to be associated with the presence of raw sewage (26). Therefore, it would seem that proper disinfection superimposed on secondary or tertiary treatment does render wastewater effluents safe for discharge into recreational and shellfish waters when a prohibited zone is maintained in the "shadow" of an effluent outfall.

Need for Disinfection

Disinfection of effluent from a given source is required whenever the processes of physical removal at the source and dilution during transit to the target are not sufficient to meet the target area requirements as stated below.

Standards Required

At the present time, a realistic standard for disinfection can be stated as follows: The disinfection of wastewater must meet the standards for indicator microogranisms when the receiving stream is used for water supply, recreation or shellfish growing.

Obviously, the above definition "is not fixed in concrete". As advanced methods for pathogen removal become available and better (in terms of logistics, economics, ecological and health side effects) disinfectants are developed, removal, disinfection and dilution can be treated as separate barrier layers in wastewater disposal and reuse. Even then it would seem judicious to prohibit water users in the immediate vicinity (in time or space) of wastewater outfalls.

Conditions for Exemption

Exemptions to the requirement for disinfection occur when natural die-away and a dilution are adequate for meeting the target area requirements or during those times when there is not potential for adverse health effects; e.g., no swimming, due to cold weather. The former case has been operative at some sewage treatment plants along the coast of Southern California which use long distance, deep ocean outfalls (27-29). The latter exception has been taken by communities such as New York City which chlorinate only during the swimming season (30).

Toxic Effects of Disinfectants

1. Residual and Reaction Products

a. Chlorine

It has recently been reported that chlorination of water and wastewater results in the formation of halogenated organic compounds that are suspected of being toxic to man.

In his pioneer study, Jolley (31) determined that under experimental conditions approximating those encountered in wastewater treatment plants, chlorine-containing organic compounds are present after chorination of the effluent. Some seventeen chlorine-containing, stable organic compounds were identified and quantified at the 0.2 to 4.3 ug/l level. A list of these chlorination products and their concentrations is given in Table 1.

Under EPA contract, Eco-Control (32) reviewed the literature for health hazards associated with these compounds or classes of compounds. Compounds listed in Table 1 fall under the general classification of (1) chlorophenols, (2) chlorobenzoic and chlorophenylacetic acids and (3) chlorinated purines and pyrimidines. It was concluded that although the first two classes of compounds should not represent significant health hazards at those concentrations, the chlorinated purines and pyrimidines could potentially exhibit some teratogenic and carincogenic activities.

Bellar et all (33) determined the nature and concentrations of organochlorine compounds in the effluent of a wastewater treatment plant receiving a mixture of domestic sewage and industrial wastes. Based on the results presented in Table II, Bellar et al concluded that the increase in chloroform concentration appears to be due to chlorination. Similar conclusions could not be reached for the other compounds listed because of small differences in the concentration levels before and after chlorination.

During the chlorine disinfection of municipal water supplies, Bellar et al (33) found chloroform, bromodichloromethane, and dibromochloromethane and assumed that these compounds are formed through the interaction of chlorine with organic compounds in drinking water. Table III lists the concentration found at differenct sampling points of a water treatment plant (see figure 1).

Rook (34) found the following compounds to be formed by chlorination of water supplies: chloroform, bromodichloromethane, dibromochloromethane, and bromoform. He further postulated that naturally occurring humic substances are precursors to the formation of these haloforms. The maximum concentrations found were: chloroform 554 ug/l, bromodichloromethane 20.0 ug/l, dibromochloromethane 13.3 ug/l, and bromoform 10.0 ug/l.

A cursory evaluation of the health effects of some of these compounds was given by Kraybill (35) and is presented in Table IV. It can be seen both bromoform and chlorodibromomethane, which are presumably formed during disinfection with chlorine, are classified as "suspect carcinogens".

A multitude of halogen-containing organic compounds has been found in water and wastewaters (36). Example of such compounds found in drinking water is given in Table V presented by McCabe and Tardiff (37). However, these compounds are not specifically mentioned here since there is yet no evidence indicating the in-situ formation of these halogenated compounds through the interaction of chlorine with organic compounds in water or wastewater.

b. Dechlorination

Dechlorination can be effected using reducing agents such as sulfur dioxide, sodium bisulfite, or sodium sulfite, activated carbon or by aeration for certain volatile forms of chlorine.

Free chlorine (HOCl and OCl) and inorganic chloramines are known to be destroyed by sulfites and activated carbon (38,39).

There is a need to evaluate the literature and perhaps conduct reasearch to determine the interaction of halogenated organics such as chloroform with dechlorinating agents of the types mentioned above. Until more is known on this subject, it cannot be stated with any certainty that conventional dechlorinating agents will efficiently remove halogen-containing organics.

c. Ozone

Ozone is used extensively in Europe for the disinfection of drinking water. Little is known of the toxicity of ozone in aqueous solutions, its interaction with organic matter in water and wastewater and the acute and chronic health effects of the reaction by-products. Additional research is needed in this area before large scale use of ozone as a substitute for chlorine disinfection on a wide scale.

d. Other Disinfectants

Bromine, bromine chloride, chlorine dioxide, iodine, permangate, silver, utlraviolet light have been used to a limited extent for disinfection purposes. Permanganate and silver have no known application in wastewaters. Drawbacks for the above include: high cost, toxic side effects, inefficiency under turbid condition, and lack of residual disinfection. The halogen disinfectants (Br, BrCl, I) will probably exhibit similar properties to chlorine in their interaction with organic compounds in water and wastewaters. Considerable work is needed to evaluate both the short and long term toxicities of these disinfectants and their reaction products.

SECTION V. EFFECTS OF DISINFECTANTS ON AQUATIC LIFE

INTRODUCTION

The present emphasis on environmental preservation and human health is resulting in an increased use of chlorine for disinfection and waste treatment. Recent investigations, including life-cycle studies with aquatic organisms, have greatly clarified the significance of chlorine toxicity. Several major projects in various stages of development or completion will add to this understanding, but sufficient data are available to permit estimates of the maximum levels of total residual chlorine (TRC) that would protect aquatic life.

As with all toxic materials, it is essential to consider potential environmental and chemical effects of toxicity. Merkens (1) states that the toxicity of chlorinated wastes in rivers will depend not only on the amount of chlorine added but on the concentration of TRC remaining in solution. He also concluded that the toxicity of TRC will depend on the relative proportions of free chlorine and chloramines. This ratio in turn depends on the amount of ammonia originally present in the water, the amount of chlorine added, pH, temperature, and the length of time over which the reaction has taken place. This study also concluded that free chlorine is more toxic than chloramines and that TRC is more toxic at lower pH (6.3 versus 7.0) because more free chlorine is present at the lower pH. Merkens concluded, however, that "the toxicity of the solution is determined in the main by the total concentration of available chorine and that the toxicities of the chloramines and free chorine must all be of the same order." Doudoroff and Katz (2) also stated that the difference between the toxicity to fish of free chlorine and chloramines is apparently not very great.

FRESHWATER

1. Effects of chlorinated wastewater treatment plant effluent.

The Michigan Department of Natural Resources (3) reported the effects on caged fish in several receiving streams below wastewater discharges. Fifty percent of the rainbow trout died with 96 hr. (96-hr TL50) at TRC concentrations of 0.014 to 0.029 mg/l; some fish died as far as 0.8 mile (1.3 km) below the outfall. These same discharges were studied when chlorination was temporarily interrupted and no mortality was observed.

Tsai (4) studied the effects on fish of 156 wastewater treatment plans in Maryland, Northern Virginia, and Southeastern Pennsylvania. All the plants discharged chlorinated municipal wastes into small streams containing fish. In most of the plants in Maryland and Virginia 0.5 to 2.0 mg/l residual.

chlorine is maintained in the effluents. Pennsylvania requires 0.5 mg/l in effluents prior to discharge to natural surface water. Tsai studied principally fish, but observed typically a clean bottom without living organisms in the area immediately below the chlorinated outfalls. Unchlorinated discharge areas were typically characterized by abundant growths of wastewater fungi. No fish were found in water with a TRC above 0.37 mg/l, and the species diversity index reached zero at 0.25 mg/l. A 50% reduction in species diversity index occurred at 0.10 mg/l. Of the 45 species of fish observed in the study areas, the brook trout and brown trout were the most sensitive and were not found at concentration above approximately 0.02 mg/l. Ten species were not found above 0.05 mg/l.

Arthur et al. (5) studied the effect of chlorinated secondary wastewater treatment plant effluent containing only domestic sewage effluent on reproduction of fathead minnows, Daphnia magna, and the scud Gammarus pseudolimnaeus. D. magna apparently was the more sensitive invertebrate species and died at a TRC concentration of 0.014 mg/l. Successful reproduction occurred at 0.003 mg/l and below. Scud reproduction was reduced at concentrations above approximately 0.012 mg/l (1.2 percent effluent). No effects on any life cycle stage, including reproduction, of the fathead minnow was observed at a concentration of 0.014 mg/l; adverse effects were observed at 0.042 mg/l. Acute toxicity studies with eight species of fish, crayfish (Orconectes virilis), scud (Gammarus pseudolimnaeus), snails (Physa integra and Campeloma decisum), and stoneflies (Acroneuria lycorias) indicated that the crayfish, snails, and caddisfly larvae were least sensitive (7-day TL50 values greater thar 0.55 mg/l). Seven-day TL50 values for the other organisms were between 0.083 and 0.261 mg/l; coho salmon and brook trout were the most sensitive. Nearly 50 percent of these observed mortalities occurred in the first 20 hr of the acute tests indicating that the lethal effect of TRC occurs rapidly.

Esvelt et al. (6,7) and Krock and Mason (8) conducted an extensive study on the toxicity of chlorinated municipal wastewaters entering San Francsico Bay and surrounding areas. They observed a significant increase in toxicity following chlorination. Chlorine toxicity was still significant in aged (up to 3 days) chlorinated wastewater, in which TRC concentrations were as high as 25 percent of the initial level. Rainbow trout was the most sensitive of the species tested, followed by the golden shiner and three-spined stickleback. A calculated chlorine residual of 0.03 mg/l, based on dilution of a measured concentration of 2.0 mg/l, reduced plankton photosynthesis by more than 20 percent of the value obtained with dilution of effluent having no chlorine residual. Dechlorination with sodium bisulfite also eliminated chlorine-related toxicity. One of the conclusions of the California study was that chlorination may be the largest single sources of toxicity in San Francisco Bay.

Martens and Servizi (9) and Servizi and Martens (10) observed mortality of salmon in receiving streams at TRC concentrations as low as 0.02 mg/l. Determinations of the effect of time on chlorine residuals were made by sample storage and lagoon retention. Lethal concentrations persisted in undiluted effluent for at least 50 hours. Twenty to one dilutions resulted in the chlorine residual declining to a non-detectable concentration after 12 hours. Studies with live cages at points downstream from the effluent demonstrated acutely lethal conditions that did not persist during periods when the chlorinator was inoperable.

An ongoing project with the City of Wyoming, Michigan sponsored by the U.S. Environmental Protection Agecny, has studied the chronic effects of various disinfection techniques on the fathead minnow. While the results are incomplete and statistically untested, it appears that the toxicity of this chlorinated effluent is similar to that described above. This study was performed at the Grandville Sewage Treatment Plant and was the first phase of this project.

As indicated previously many wastewater treatment plants are required to maintain a residual chlorine concentration of 0.5 to 2.0 mg/l. Most operators use the orthotolidine method which has been frequently shown to be inaccurate resulting in much higher concentrations than necessary for adequate disinfection. This compounds the toxicity problems in the receiving waters. Total residual chlorine concentrations in 20 Illinois effluents ranged from 0.98 to 5.17 mg/l (11). A similiar study at 22 plants in southern Wisconsin resulted in observed concentrations of TRC between 0.18 to 10.3 mg/l (12). Both studies demonstrated that the orthotolidine methods provided the poorest results when compared with other methods such as the amperometric titration technique. Other studies (9,10) reached the same conclusion that the commonly used orthotolidine method is inadequate to determine TRC in wastewaters or receiving streams.

2. Effects of dechlorinated wastewater treatment plant effluent.

Several of the cited studies also evaluated the effect of various dechlorination techniques on the toxicity characteristic of chlorinated wastes. Under laboratory bioassay conditions dechlorination with sodium thiosulfate at several Michigan plants resulted in no acute toxicity tests by Arthur et al. (5) using sulfur dioxide for dechlorination indicated that the toxicity was greatly reduced or eliminated. In the latter study the highest effluent concentration tested in the chronic studies was 20 percent; 100 percent effluent was the highest concentration in the acute studies. Preliminary results at the Grandville, Michigan plant have not been statistically analyzed but there may have been slight chronic effects at effluent concentrations of 100 and 50 percent dechlorinated waste. No effect was indicated at 25 percent. During this study there also may have been adverse effects in the undiluted, untreated waste.

The Canadian studies (9,13) observed no acute salmon mortality in undiluted effluent after dechlorination by storage in a lagoon. They also stated that several California cities will soon be dechlorinating with sulfur dioxide. The toxicity studies in California (6,7,8) observed that acute mortality in undiluted effluent was totally eliminated by dechlorination with sodium bisulfite.

3. Effects of alternative disinfection of wastewater treatment plant effluent.

a. Ozone

There is a lack of toxicity data for ozonated effluent at this time. No measurable toxicity to aquatic life was found in chronic tests by Arthur et al. (5) using a 20% concentration of waste disinfected with ozone. Unrealistically high concentrations of ozone, relative to that needed for disinfection, were necessary to maintained concentrations of 0.2 to 0.3 mg/l in a testing system where acute mortality occurred. Typically, ozone dissipated rapidly between the contact chamber and the test chambers. Preliminary results of comparable studies at the Grandville, Michigan waste treatment plant indicate that the ozonated effluent had no significant effect on fathead minnow reproduction, growth, or survival.

During a 6-week pilot plant study by Nebel et al. (13) there was no mortality of bass, perch, minnows, and goldfish exposed to undiluted ozonated effluent at the Fort Southworth treatment plant in Louisville. These same species did not survive in the non-disinfected secondary effluent. Spawning in the undiluted, ozonated effluent at Grandville was apparently increased over that in the raw effluent.

B. Bromine chloride

The only significant data on the toxicity of brominated wastewater effluent are preliminary data from the Grandville project. The acute toxicity of this effluent is similar to that for chlorine but the toxicity of this effluent declines at a much greater rate than that for chlorine. The same is true for the chronic test. A 25 percent effluent concentration (0.18 mg/l bromine residual) had no chronic effect on reproduction of the fathead minnow, whereas a 20 percent effluent concentration of chlorinated waste (0.104 mg/l chlorine residual) killed all the test fish.

The principal characteristic of brominated effluent is that initially it is as toxic as chlorinated effluent but its toxicity becomes negligible in a matter of minutes whereas residual chlorine toxicity may persist for many hours.

MARINE

1. Effects of chlorinated wastewater treatment plant effluent.

Although limited information does exist on the effects of chlorine residuals on marine and estuarine life, few data are available on the effects of the wide spectrum of chlorinated hydrocarbons which are introduced into marine ecosystems by discharge of chlorinated municipal treatment plant effluents. Studies to identify these compounds, their rates of formation and potential impact on marine communities have only recently been initiated.

The results of a study by Holland et al (14) indicate that 0.25 mg/l chlorine was lethal to chinook salmon. At an exposure time of 23 days, the maximum non-lethal concentration of residual chlorine for pink salmon and coho salmon in sea water was 0.05 mg/l. According to the authors, no chlorimines were formed in sea water containing 0.05 to 0.5 mg/l chlorine and 3 mg/l ammonia. Alderson (15) found that the 48 and 96 hr TLm for plaice larvae was 0.32 and 0.026 mg/l free chlorine respectively. After 96 hours exposure to 0.03 mg/l chlorine, the feeding rate of surviving larvae gradually decreased by 50 percent. Eggs were not affected by exposure to 0.075 and 0.04 mg/l chlorine solution for 8 days indicating that the protection of the egg membrane allows normal development over relatively long periods even at chlorine concentrations which would be rapidly lethal to hatched larvae. The 72 hr and 192 hr TLm for the eggs was 0.7 and 0.12 mg/l respectively.

Muchmore and Epel (16) found that the fertilization success of gametes of the sea urchin Strongylocentrotus purpuratus exposed to a 10 percent unchlorinated sewage-seawater mixture was reduced by 20 percent. Chlorinated sewage further reduces fertilization success in concentrations as low as 0.05 mg/l available chlorine. These results indicate that the use of chlorine disinfection could contribute to reproductive failure in external fertilization of marine invertebrates in the vicinity of sewage outfalls.

Galtsoff (17) observed that the pumping activity of oysters exposes to 0.01 to 0.05 mg/l chlorine was reduced. Effective pumping could not be maintained at a concentration of 1.0 mg/l.

Tsai (18,19) observed decreases in the abundance and occurance of brackish water species including the common sucker, Catastomus commersonni, the minnows, Notropis cornutus, N. analostanus and N. prooni, and the catadromous eel, Anguilla rostrata, in certain areas of the Upper and Little Patuxent Rivers receiving chlorinated sewage treatment effluents.

Additional evidence for the effects of chlorine on marine environments may be found from studies of the effects of chlorination of sea water on the survival of fouling organisms and on phytoplankton production. Waugh (19) observed no significant difference in the mortality of oyster larvae, Ostrea edulis, exposed to 5 mg/l chlorine for 3 minutes at ambient temperature compared to control mortality. Exposure of larvae to thermal stress (10 C above ambient) and 10 mg/l chlorine for 6 to 48 minutes also had no significant effect on survival, 46 and 64 hours after treatment. Barnacle nauplii, Elminius modestus showed more acute sensitivity to chlorine. Residual chlorine concentrations in excess of 0.5 mg/l caused heavy mortality and reduced growth for survivors.

McLean (21) simulated the conditions encountered by marine organisms passing through a power plant on the Patuxent River, Maryland. Intake chlorination to 2.5 mg/l residual, entrainment for approximately 3 minutes and sustained exposure to elevated temperatures for up to 3 hours were used as experimental parameters. While barnacle larvae, Balanus sp. and copepods, Acariatonai, were not affected by a 3 hour temperature stress of 5.5 and 11 C above ambient; exposure to 2.5 mg/l residual chlorine for 5 minutes at ambient temperatures caused respective mortality rates of 80 and 90 percent 3 hours after exposure. Grass shrimp, Palaemontes pugio, and the amphipod, Melita nitida, showed a delayed death response after exposure to 2.5 mg/l residual chlorine for 5 minutes. Nearly 100 percent mortality was observed for both species 96 hours after exposure to the chlorine residual.

Carpenter et al. (22) investigated the effects of chlorination on phytoplankton productivity. An 83 percent decrease was observed in the productivity of phytoplankton passed through the cooling systems of a nuclear generating plant on Long Island Sound which received 1.2 mg/l chlorine at the intake. Essentially no decrease in productivity was observed when phytoplankton passed through the cooling system without addition of chlorine. Hirayama and Hirano (23) found that Skeletoneme costatum was killed when subjected to 1.5 to 2.3 mg/l chlorine for 5 to 10 minutes.

Gentile et al. (24,25) at the National Marine Water Quality Laboratory, West Kingston, Rhode Island, observed a 55 percent decrease in the ATP content of marine phytoplankton exposed to 0.32 mg/l chlorine residual for two minutes and 77 percent decrease after 45 minutes of exposure to chlorine concentrations below 0.01 mg/l. A 50 percent depression in the growth rates of 10 species of marine phytoplankton exposed to chlorine concentrations ranging from 0.075 to 0.25 mg/l for 24 hours was also measured.

2. Effects of dechlorinated wastewater treatment plant effluent.

No information is available on the effects of dechlorinated effluents on marine and estuarine organisms. Extrapolation of freshwater data to marine ecosystems would indicate, however, that the dechlorination of effluents would reduce chlorine toxicity significantly.

3. Effects of alternative disinfection of wastewater treatment plant effluent.

Research on the effects of alternative disinfectants such as ozone is only in preliminary stages relative to marine ecosystems. The agents resulting from ozonation and UV irradiation have been neither identified nor analyzed for ecological impact.

RECOMMENDED CRITERIA

1. Freshwater.

Several reviewers of chlorine toxicity have recommended numerical criteria for continuous concentrations of TRC that would not adversely effect aquatic popultions. Basch and Truchan (26) recommended maximum concentrations of 0.02 and 0.005 mg/l for warmwater and coldwater fish, respectively. EIFAC (27) has suggested criteria dependent upon pH and temperature with an acceptable upper limit of 0.004 mg HOCl/l (TRC from 0.004 mg/l at pH of 6.0 and 5 C to 0.121 mg/l at a pH of 9.0 and 25 C). A third review by Brungs (28) has recommended a criterion of 0.01 mg/l for warmwater fish and 0.002 mg/l for coldwater species and the most sensitive fish food organisms.

These criteria may eventually be influenced by ongoing studies that are investigating chlorinated residues in fish tissues resulting from chlorination of waste effluents.

No criteria can be considered as yet for ozone and bromine chloride although available data indicated that the toxicity of effluents disinfected with these materials is less than with chlorinated effluent.

Similarly, no criteria for various dechlorinated chemicals (e.g., sodium bisulfide, sodium thiosulfate, and sulfur dioxide) can be proposed at this time. No adverse acute effects of dechlorination have been observed. Preliminary data indicate possible slight chronic effects but only in 100 and 50 percent raw dechlorinated effluent.

2. Marine

Although chlorination is used to eliminate undesirable levels of organisms that would degrade water uses, it is evident that the effects of chlorine on desirable marine and estuarine species is a serious hazard. No information is available on the effects of toxic chlorinated products on marine life. It appears, however, that free residual chlorine in sea water in excess of 0.01 mg/l can be hazardous to marine life. Additional study of many organism types under a wide variety of environmental conditions is needed to establish a recommended value for chlorine.

CONCLUSIONS

1. Trout, salmon, and some fish-food organisms are more sensitive than warmwater fish, snails, and crayfish.

2. Chronic toxicity effects of TRC on growth and reproduction occur at lower concentrations than those causing mortality.

3. Dechlorination with sodium biosulfite, sodium thiolsulfate, and sulfur dioxide, or certain other compounds, greatly reduces or eliminates toxicity caused by TRC.

4. Brominated effluent may be as toxic as chlorinated effluent but its toxicity is reduced to no-effect concentrations in a much shorter period of time than chlorinated effluent.

5. No acute adverse effects of ozone were observed in as high as 100 percent effluent.

6. Non-disinfected secondary domestic effluents have only slight toxicity to freshwater organisms at concentrations as high as 100 percent effluent.

7. Chronic toxicity effects of TRC on marine organisms occur at lower concentrations than those causing mortality.

8. Sublethal concentrations of chlorine can reduce productivity of marine phytoplankton.

9. Larval stages of marine forms appear to be more sensitive to chlorine than either the egg or adult stages.

SECTION VI - DISINFECTION PROCESS ALTERNATIVES

Program Background

The Municipal Pollution Control Division and the Ecological Processes and Effects Division have supported an active program in developing new disinfectants and techniques for application to waste treatment plants effluents and combined sewer overflows. Many of the completed projects have provided the basis for the present research program and have greatly contributed to the present state of the art. A list of completed and on-going projects is presented in the Appendix to give the reader an overview of the activity in this area.

An important and major part of the program in this area is an on-going grant with the city of Wyoming, Michigan. The project was designed to test the toxicity of residual chlorine to aquatic life; investigate alternative methods for disinfection of wastewater; and test the toxicty of those methods to aquatic life. The alternative processes being studied are disinfection with ozone and bromine chloride, and the neutralization of residual chlorine in chlorinated effluent with sulfur dioxide. The study is a cooperative effort between the Grand Valley State Colleges, Allendale, Michigan, and the cities of Wyoming and Grandville, Michigan. Funding for the bromine chloride disinfection study has been totally provided by the Dow Chemical Company and Ethyl Corporation. The Grace Chemical Company has provided ozonation equipment and information dealing with the application of ozone to wastewater.

The following is a discussion on the alternative processes that have been developed and their general standing in regard to immediate and future application.

OPERATIONAL PROCESSES

Liquified Chlorine Gas (Molecular Chlorine)

General

Liquified chlorine gas (subsequently referred to as chlorine) is soluble in water (0.0608 lbs/gal. at 20°C). For practical purposes the storage life of chlorine is essentially unlimited. It assumes two forms in wastewater that account for most of its disinfecting activity:

1. HOCl (hypochlorous acid) which is extremely effective in killing both bacteria and viruses.

2. Monochloramine, the dominant form in wastewater, a persistant but relatively slow acting disinfectant.

The reason for the dominance of monochloramine is that practically all wastewater contains ammonia and most of the chlorine applied is very rapidly converted to monochloramine at normal wastewater pH of slightly above 7.0. Other chlorinated compounds such as organic chloramines are formed but these are of little germicidal importance in the disinfection of wastewater.

Status

Chlorine is currently the predominant wastewater disinfectant and it is essentially the exclusive disinfectant if one includes its counterpart, sodium hypochlorite, which will be covered subsequently in a separate section. A minimum chlorine contact time with a specified chlorine residual is included in some state standards. Others rest on EPA regulations or specify that certain bacteriological standards be met.

Equipment and Chemical Suppliers

There is a wide variety of sources of equipment for adequately applying and controlling the use of chlorine for disinfection of wastewater. The field is extremely competitive. There was some concern for availability of adequate supplies of both chlorine and shipping containers early in 1974 (1). In the EPA Disinfection Policy Task Force meeting on July 9, 1974, it was reported that there was no shortage of either containers or chlorine for water and wastewater disinfection.

Safety

Liquid chlorine is a hazardous chemical and chlorine gas is toxic and can cause death by suffocation (2). It irritates the respiratory tract mucous surfaces and the skin. Direct contact with liquid chlorine can cause serious burns. Safey equipment (gas masks) is required for emergency protection in all potentially dangerous areas. Safety precautions must be excercised in all shipment, storage, and use areas. The liquid vaporizes at atmospheric pressure and ambient temperatures. The gas is 2-1/2 times as heavy as air and will persist in low areas.

Reliability

Chlorine is generally a reliable disinfectant. There is clear-cut evidence that chlorination of wastewater destroyed enteric pathogenic bacteria. In a study on the occurrence of Salmonella in the receiving stream after wastewater chlorination, Salmonella were not detected in either chlorinated effluents or the receiving stream during a 7-month period when effluents were chlorinated. After chlorination was discontinued, Salmonella were isolated. When chlorination was resumed, however, they were not detected in samples collected during a 4-week period (3).

The value of the coliform test is indicated by the fact that "... epidemics of hepatitis originating in chlorinated water supplies judged satisfactory by the coliform test have not been reported except where obvious deficiencies in chlorination practice were shown or suspected" (4). Apparently, the coliform test provides a good measure of protection against the one virus disease that has frequently been the cause of waterborne epidemics. Basically, its effective use for disinfection of wastewater requires an understanding of the disinfecting efficiency of hypochlorous acid (HOCl) hypochlorite ion $(OCl)^-$ and chloramines (4). The primary disinfectant form of chlorine in current wastewater treatment practice is monochloramine and other forms of combined chlorine. Disinfection of secondary effluents can reliably meet stringent bacteriological standards. Only limited information is available on the virucidal effect of monochoramine and what is available indicates that it is a slow acting virucide (5). To ensure adequate protection from viruses, long-term exposure to monchloramine is required, whereas chlorination to breakpoint (HOCl residual) will rapidly destroy both viruses and bacteria (6).

Research

The present research program is implementing a comprehensive project to improve chlorine contactor design and mixing under EPA Grant No. 803459, "Reduction of Unit Toxicity Emission Rates from Wastewater Treatment Plants by Optimization of the Chlorination Process." This will include preparation of a design manual for chlorine contact systems. An improved understanding of the effect of combined chlorine on viruses is being sought under EPA Grant No. 800370, "A Comparative Study of the Inactivation of Viruses in Wastewater by Chlorine and Chlorine Compounds." A search is underway for "New Microbial Indicators of Disinfection Efficiency," jointly funded by EPA and the Army under an Interagency Agreement EPA-LAG-D4-D432 (formerly EPA Grant No. R-800912).

Improved technology for application of chlorine to effluents from lagoons, oxidation ponds, and related treatment processes will be investigated under a contract with Utah State University to "Determine Chlorination Requirements to Satisfactorily Disinfect Lagoon Effluent to Meet Secondary Treatment Standards." Award of contract is pending. There is a need for improved instrumentation for monitoring residual chlorine and automation for better control of dosage response in relation to residual chlorine.

Costs

With the exception of chlorine much of the cost information presented must be considered tentative at this time. For example there have been no full scale plant demonstrations to support cost analysis for wastewater disinfection with ozone, bromine chloride and ultraviolet light or dechlorination with carbon. The dosage assumed for chemical disinfectants are 8 mg/l to achieve disinfection. Costs of disinfection with chlorine are presented in Table I (7).

Table I

Chlorine Disinfection Cost

Plant Size, MGD	1	10	100
Capital Cost, $	60,000	190,000	840,000
Disinfection Cost, ¢/K Gal	3.49	1.42	0.70

Sodium Hypochlorite (NaOCl)

General

The disinfecting potency of 1.0 mg/l of chlorine derived from sodium hypochlorite is just as effective as an equivalent amount of chlorine as hypochlorite ion $(OCl)^-$ dervived from liquified chlorine gas. Either chlorine gas or sodium hypochlorite in aqueous solution at concentrations used for wastewater disinfection, assume the same form and are equally available to react with ammonia or other wastewater components (4). Sodium hypochlorite is only available as an aqueous concentrate. The optimum concentration of sodium hypochlorite in terms of maximum concentration and stability is 15 percent (8). Sodium hypochlorite solutions must be protect from freezing. The concentrated solution is highly corrosive to most common metals and wood. Sodium hypochlorite solutions lose oxidizing power during storage. A solution of sodium hypochlorite that contains 15 percent of available chlorine by volume when stored at 75°F will lose half of its original activity in 100 days (9). Storage above 85°F is not recommended. Lower concentrations will not deteriorate so rapidly, but increased storage capacity is required.

Status

Increasingly, certain wastewater treatment plants are turning to the use of sodium hypochlorite because it is safer than liquified chlorine gas (8). Two examples suffice to illustrate this point, namely, the cities of New York and Chicago. A limited number of other plants are making the change for the same reason - to avoid storage of liquified chlorine gas in plants with close proximity to heavily populated areas.

Equipment and Chemical Supplies

With the exception of the feeder, storage, and some piping, a hypochlorination system is very similar to that for a system using liquid chlorine (8). Equipment is available for on-site generation of sodium hypochlorite or the chemical can be purchased and stored in tanks; therefore no major supply problems are anticipated.

Availability of sodium hypochlorite should be essentially the same as for chlorine. Chlorine gas is produced by electrolysis of brine with sodium hydroxide as a by-product. Sodium hypochlorite is produced by recombining the chlorine with sodium hydroxide.

Safety

The primary reason for using sodium hypochlorite instead of liquified chlorine gas is because it is safer. "Neverthless, it should be clearly understood that sodium hypochlorite is hazardous and proper safety precautions should be employed. However, a number of large users, including the cities of New York and Chicago, are apparently willing to pay the premium for the greater safety aspects of this product in comparison to liquid chlorine" (8).

Reliability

The active forms of chlorine derived from sodium hypochlorite and liquified chlorine gas are the same when applied to wastewater. Accordingly, the advantages and disadvantages with regard to disinfection reliability are essentially the same for sodium hypochlorite and liquified chlorine gas.

Research

Needs essentially the same as for liquid chlorine.

Costs

When considering the entire system of piping, storage tanks, diffusers and instrumentation and feeders, there is usually only a small percentage of difference in capital cost of liquid chlorine and sodium hypochlorite systems (9). Current costs of sodium hypochlorite indicate that available chorine as sodium hypochlorite costs approximately 2.5 to 10 times more than liquified chlorine gas depending on the volume treated (10). For comparison, apply these factors to the disinfection cost in Table I.

Dechlorination with Sulfur Dioxide (SO_2)

General

Since chlorination of wastewater causes chlorine residuals that can be toxic to aquatic life, dechlorination may have to be practiced in some situations.

Sulfur dioxide is the best direct reacting chemical agent available for wide scale use in dechlorinating wastewater. It is available commercially as the liquified gas and is much more soluble than chlorine in water (1.0 lb/gal. at 60°F). Upon dissolving sulfur dioxide in water a weak solution of sulfurous acid is formed. The dechlorination reaction of sulfur doxide with both free

and combined chlorine residuals is nearly instantaneous (11). Contact chambers are not necessary but rapid and complete mixing at the point of addition is important. The reaction weight ratio of sulfur dioxide to chlorine is 0.9:1.0 which converts chlorine to the choride ion. The sulfur dioxide dosage needed is that sufficient to neutralize the residual chlorine. Sulfur dioxide appears to be effective in preventing toxic stress to receiving water biota. There is no reason to expect that its use will exert any effect on chlorinated organic compounds resulting from disinfection with chlorine. However, research is required to determine if this assumption is correct.

Status

Sulfur dioxide has long been used to neutralize chlorine in treatment of drinking water, but its use for dechlorination of wastewater is just getting underway. Information obtained in October 1974 on four wastewater treatment plants with average daily flows ranging from 4.0 mgd to 160 mgd indicated no serious problems in dechlorinating with sulfur dioxide. Of these plants, the Sacramento City plant (flow 50 mgd) had been using sulfur dioxide dechlorination for 9 months (12).

Equipment and Chemical Supplies

Equipment for feeding sulfur dioxide is very similar to that used for chlorine and no serious difficulties in the supply situation for equipment or sulfur dioxide are anticipated.

Safety

Sulfur dioxide is a hazardous highly corrosive and extremely irritating gas that causes skin and eye burns and damages mucous surfaces. It is self-warning. It is less prone to rapid volitalization than chlorine (vapor pressure of sulfur dioxide at 70°F is 35 psi while the corresponding value for chlorine is 90 psi). Handling precautions are similar to chlorine but the lower pressures of sulfur dioxide are less prone to cause leakage problems.

Reliability

Sulfur dioxide is a reliable chemical agent for removing residual chlorine from water and wastewater. As sulfur dioxide is a reducing agent, careless operation can lead to reduced dissolved oxygen content of effluents. As a result, some states are requiring reaeration to increase the dissolved oxygen content of the effluent when sulfur dioxide is used to dechlorinate.

Research

An important area where research is needed is in the study of aftergrowth following dechlorination. Complete removal of bactericidal effects may result in increased aftergrowth. This problem is likewise anticipated with disinfectants such as ozone and ultraviolet light which leave no lasting residual.

Costs

Costs for both dechlorination with sulfur dioxide and restoration of dissolved oxygen content are presented in Table II and III. To obtain the total cost of disinfection, the chlorination cost in Table I must be added to the dechlorination and the oxygen restoration cost in Tables II and III (7).

Table II

Dechlorination with Sulfur Dioxide Cost

Plant Size, MGD	1	10	100
Capital Cost, $	11,000	29,000	94,000
Disinfection Cost,. ¢/K Gal	0,88	0.33	0.19

Table III

Cost for Post Aeration Following Sulfur Dioxide Dechlorination

Plant Size, MGD	1	10	100
Capital Cost, $	49,000	140,000	650,000
Disinfection Cost, ¢/K Gal	3.29	0.64	0.30

ALTERNATIVE PROCESSES

Dechlorination with Activated Carbon

General

Chlorinated effluent can be dechlorinated by treating the effluent with activated carbon. This technique is a physical process in which chlorinated amines, free chlorine and chlorinated organics are removed by sorption on the carbon. This polishing step not only alleviates the problem of toxicity associated with chlorine but it also removes residual refractory organics and may remove some of the potentially toxic chlorinated organics.

Status

Activated carbon is used as a tertiary treatment stage for reducing the chemical oxygen demand (COD) of wastewater at several waste treatment facilities. This technology is applicable for the design and operation of carbon systems for dechlorination (13). The practice of dechlorination with activated carbon is used as a supplementary treatment for water supply by the brewery and soft drink industries (14). Its use in dechlorinating wastewater treatment has been limited to a pilot plant evaluation at Owosso, Michigan (15). The results from the Owosso facility proved the feasibility of this process to adequately remove the free and combined chlorine from the effluent. However a full scale demonstration is required to establish the cost of dechlorinating with carbon. This process is the most costly of the many alternatives in regard to both capital and operating costs.

Equipment and Chemical Suppliers

As mentioned above, activated carbon is used for COD reductions as a tertiary treatment stage. The equipment and material (carbon) is available for ready implementation. The mode of operation in which the effluent flows thru a static bed of carbon reduces the operating difficulties normally associated in dechlorination with chemicals, such as sulfur dioxide. Biological growth on carbon may reduce the dissolved oxygen level of the effluent and require post aeration treatment before discharge.

Safety

The operation of a carbon column requires no special precautions. However when it becomes necessary to perform internal maintenance or inspect the inside of the carbon column, special safety precautions must be taken to avoid CO and CO_2 inhalation or an atmosphere devoid of oxygen.

Reliability

The Owosso, Michigan pilot plant study for dechlorinating wastewater with carbon showed that the carbon consistently removed the free and combined chlorine. Long term tests are still required to determine the influence of organic loadings on the efficiency of the chlorine removals and to determine if aftergrowth occurs on the carbon beds.

Research

Dechlorination with carbon is a medium priority process in the program to develop alternatives to chlorination. Cost estimates have shown this process to be the most costly alternative. More significantly, the cost estimates assume that the carbon will perform for several years before replacement, thereby eliminating carbon regeneration facilities. This assumption needs verification before such a system can be placed into operation. Since the costs for dechlorination with carbon are significantly higher than other alternaive processes, carbon dechlorination research is classified at a medium priority level.

Costs

The cost of dechlorinating with carbon is shown in Table IV (7). The cost for chlorination is included in the capital and disinfection cost for dechlorination with carbon.

Table IV

Dechlorination with Carbon

Plant Size, MGD	1	10	100
Capital Cost, $	640,000	2,800,000	8,400,000
Disinfection Cost, ¢/K Gal	19.00	8.60	3.28

Ozone

General

Because of its high oxidation potential, ozone has received the most attention as a disinfectant alternative to chlorine. Ozone is a chemical disinfectant that may derive its germicidal properties from the foramtion of nascent oxygen in the breakdown of ozone. In addition to disinfection, ozone reduces the color and odor of wastewater. Although ozone is 13 times more soluble in water than oxygen, it is difficult to dissolve more than a few mg/l of ozone because the ozone gas concentration during generation is between 1 and 3 weight %. Ozone decomposes in water to form molecular oxygen.

Status

Ozone has been used for sixty years to treat water supplies in Europe and Canada. Its use in wastewater applications has been limited to pilot plant studies to establish feasibility, reliability, process limitations and cost information.

Although there are no full scale plants using ozone to disinfect wastewaters at this time, there are five locations (Springfield, Missouri; Meander Lake, Ohio; Estes Park, Colorado; Indiantown, Florida; Woodlands, Texas) that have specified ozone for the disinfection stage. Several of these plants are now under construction and all five locations have included filtration as a pretreatment stage for ozonation.

Equipment

Ozone generation consumes more energy than other disinfectants. It is produced on-site by the application of an electrical discharge across oxygen or air. This phase is being gradually improved by the many manufacturers of ozone equipment. At present, approximately 6 kilowatt hours of power are required to generate one pound of ozone from pure oxygen; whereas 12 kilowatt hours are required to generate one pound of ozone from air. For comparison, chlorine uses 1.3 kilowatt hours of electricity to produce one pound of chlorine.

Safety

Ozone is a toxic gas that requires special design considerations to prevent its escape into an operating area. Vent gases must be treated to convert the ozone to oxygen before releasing the gas into the atmosphere. The maximum allowable concentration for an eight hour day exposure of ozone to humans is 0.1 ppm. However, the odor of ozone is readily detected. The olfactory threshold odor concentration for the general population is 0.02 to 0.05 ppm, which enables operating personnel to take corrective action on sensing ozone (17).

Reliability

Recent pilot plant studies at Wyoming, Michigan, and Chicago, Illinois (18) have shown that it is difficult to disinfect secondary effluents with ozone and consistently meet nominal bacteriological standards. Tertiary treatment is required. Filtration has been shown to be an effective treatment stage to enhance the disinfection efficiency of ozone.

Research

The EPA research program investigating alternatives in the disinfection of wastewater has assigned ozone a high priority. Work is underway to optimize utilization by improving various contacting systems. Research plans also call

for demonstrating ozone at two of the five previously listed sites. One site will evaluate ozone produced from pure oxygen and the other site will evaluate ozone produced from air to obtain comparative cost data for ozone application as a disinfectant.

Research is still required to find a parameter for controlling ozone dosage. Present technology utilizes a constant ozone dosage which results in excessive ozone comsumption or inadequate disinfection.

Residual oxidation products need to be investiaged to determine if toxic compounds are formed when the reaction of ozone with organics do not proceed to completion (CO_2 and H_2O).

Costs

The costs for disinfecting wastewater with ozone generated from air and from oxygen are shown in Table V.

Table V

Ozone Disinfection Cost

Ozone Generated from Air			
Plant Size, MGD	1	10	100
Capital Cost, $	190,000	1,070,000	6,880,000
Disinfection Cost, ¢/K Gal	7.31	4.02	2.84
Ozone Generated from Oxygen			
Capital Cost, $	160,000	700,000	4,210,000
Disinfection Cost, ¢/K Gal	7.15	3.49	2.36

Ultra Violet (UV) Irradiation

General

Ultraviolet light is a germicide that is absorbed by organic molecular components essential for the cell's biological functioning. The excitation of the molecules causes disruption of unsaturated bonds that produces a progressive lethal biochemical change. For most species, the bactericidal effect

is a function of wave length and is greatest between 2500 and 2600 angstroms (A). With the advent of low-pressure mercury lamps approximately 85% of the lamp's energy is emitted at 2537 A (19).

For UV to be an effective germicide, the energy dosage must reach the organism. Some of the factors that may effect the penetration of UV energy into water are turbidity, color and organic compounds.

Status

UV is used as a disinfectant for dimineralized water systems. It is used for disinfecting potable water systems in overseas hotel, cruise ships restaurants and vacation camps. There are many industrial and product water applications that use UV, such as breweries, pharmaceutical manufacturers, and fish hatcheries (20).

UV has not been studied extensively as a disinfectant for wastewater; however, its feasibility was demonstrated at 40,000 GPD at St. Michaels, MD (21). Its reliability was highly dependant upon effluent quality. Additional research is required to establish minimum pretreatment requirements to optimize design parameters, such as UV dosage, hydraulics, contact time and energy requirements.

There is under construction a 2 MGD treatment plant with UV disinfection at a new community development near Rochester, N.Y. As with ozone, the facility will utilize filtration as a tertiary treatment stage prior to UV disinfection. This system is scheduled to go on stream at minimum flows during the spring of 1975. Chlorination facilities have been included at the site to serve as a backup disinfection process.

Equipment

There are numerous suppliers of UV equipment which will ensure a competitive market if UV surfaces as a viable alternative. The equipment manufacturers have made significant product improvements in regard to equipment, maintenance, contact, and dosage. The manufacturers incorporate a continuous UV monitor to measure transmission, which can serve as a parameter to monitor the disinfection.

Safety

The operation of a UV system can produce ozone and safety precautions covered under ozone may also be required for UV systems. The newer designs of UV equipment have enclosed chambers to protect against aganinst irradiation exposure which can be harmful to the eyes and skin.

Reliability

The small plant study at St. Michaels, Md. showed that good quality effluent could be disinfected with UV, however, tertiary treatment may be required to provide adequate disinfection whenever the effluent is high in solids or turbidity. Additional research is needed to provide process and cost optimization to ensure adequate disinfection with minimum treatment stages.

Research

The EPA research program has initiated a study of UV at Dallas, Texas to evaluate some of the latest equipment with various pretreatment stages and to determine the most cost effective design combination. The facility under construction near Rochester, N.Y. will be considered as a potential demonstration site to establish cost for UV disinfection.

Costs

The estimated cost for disinfecting wastewater with UV is shown in Table VI.

Table VI

Estimated Disinfection Costs with UV

Plant Size, MGD	1	10	100
Capital Cost, $	71,000	360,000	1,780,000
Disinfection Cost, ¢/K Gal	4.19	2.70	2.27

Bromine Chloride

General

Bromine chloride is a chemical disinfectant, and is similar to chlorine in its germicidal qualities. One of its advantages is that bromamines, formed as a reaction product of hypobromous acid with ammonia, are also effective germicides. In fact, bromamines are far superior to chloramines in bactericidal and virucidal activity. In addition bromamines are less stable in water and break down to form bromide salts (22).

Status

Bromine chloride is the newest candidate in search of an alternate disinfectant. Its applicability as a disinfectant has progressed rapidly by the research activity of its manufacturers. The manufacturers have performed bench scale feasibility studies on bromine chloride and moved rapidly into pilot plant evaluations, by joint funding with EPA on the bioassay and disinfection study at Wyoming, Michigan. At the present time, there are no bromine chloride facilities in operation nor are there any in the design phase; however the State of Maryland is actively searching for a potential site to demonstrate the effectiveness of bromine chloride as an alternate to chlorine.

Equipment - Chemical Suppliers

Existing chlorination facilities would require only minor modifications to convert from chlorine to bromine chloride.

There are three known manufacturers of bromine chloride. Each of the three would actively promote bromine chloride for wastewater disinfection if the product showed promise of replacing chlorine at specific locations. Bromine chloride development as a disinfectant was initiated by Dow Chemical Co. when their marketing studies indicated that bromine would be available for other uses as the quantity of leaded gasoline decreases. Presently 55 to 60% of the bromine goes toward the production of ethylene dibromide (EDB), a lead scavenger in leaded gasoline. Recent studies indicate that the decay in EDB demand amounts to 5% a year. We may assume that BrCl supplies are limited now and will be limited in the near future. According to the manufacturer, "Requests for the chemical will be handled on an individual basis."

Safety

Bromine chloride requires the same care in handling as chlorine. As such the same precautions that are used in shipping, handling, and storing chlorine are required for bromine chloride.

Reliability

The pilot plant work at Wyoming, Michigan, has shown that bromine chloride is an effective disinfectant requiring no pretreatment for an activated sludge effluent. Bromine chloride can accomplish the same degree of disinfection as chlorine with a lower final halogen residual, but the minimum level has not been established.

Research

Additional research is required to optimize bromine chloride contact systems and to establish a minimum effective halogen residual. The toxicity of brominated organic compounds is generally greater than the corresponding chlorine compounds and additional studies will be required to determine the health effect consequences. Since its chemical behavior is similar to chlorine, its development has progressed more rapidly than other alternatives. To take advantage of the potential for lower halogen residuals, instruments need to be developed to ensure adequate monitoring of the effluent. Because of the potential commercial applicability of bromine chloride, the manufacturers have made a major contribution to its accelerated development.

Costs

The cost of disinfecting wastewater with bromine-chloride is shown in Table VII. A cost summary is shown in Table VII listing the disinfectants with their capital and total disinfection costs.

Table VII

Bromine Choride Disinfection Cost (7)

Plant Size, MGD	1	10	100
Capital Cost, $	47,000	129,000	414,000
Disinfection Cost, ¢/K Gal	4.52	3.04	2.65

OTHER POTENTIAL DISINFECTANTS

Chlorine Dioxide

Chlorine dioxide (ClO_2) is one of the newer halogen disinfectants that has shown promise for use in water and wastewater treatment. It is a powerful oxidizing agent and an excellent disinfectant.

Chlorine dioxide is unstable and extremely corrosive. In practice, it is usually generated from the reaction between sodium chorite solution and chlorine in contact with the water to assure that the gas remains in solution to avoid explosion hazard. Sodium chlorite (NaClO), from which the gas is usually generated, is also explosive and the hazards of handling chlorine have already been listed. Proper handling minimizes these hazards but responsible personnel are required where it is used.

The lack of an adequate method for accurately determining low residual concentrations of chlorine dioxide is a serious drawback. Because it is such a strong oxidizing agent, more ClO_2 than chlorine may be required to disinfect wastewater.

Factors other than the cost of the chemicals used may govern the expense of wastewater treatment. Here, however, only cost of materials is considered. The cost of $NaClO_3$ and Cl_2 required to produce one pound of ClO_2 is about 13 times more than one pound of Cl_2.

Lime at pH 11.0 or Higher

It is unlikely tha lime would be seriously considered for disinfection only. However, lime has pronounced potential for combined treatment and disinfection of wastewater.

Results from EPA sponsored studies under Grant No. 16100 PAK, "Lime Disinfection of Bacteria at Low Temperature," are indicative of the effectiveness of lime as a disinfectant. Even in the presence of relatively high concentrations of organic matter and under the adverse conditions of low temperature sewage can be disinfected to a safe level by lime treatment of pH 11.5 or 12.0. A variety of generic types of bacteria can be destroyed during lime treatment as evidenced by the large reductions in total and fecal coliform content of both the effluent and the sludge. The process of disinfection can be completed within a relatively short time period (30 minutes or less), even at 1^{o} C. Additional benefits that can be realized from lime treatment are reduction in organic materials and phosphorus. If the removal of organic chemicals and phosphorus is not necessary, the cost of disposing of the sludge resulting from lime treatment would have to be considered as part of the disinfection cost.

Bromine

Bromine is a liquid at atmospheric pressure and is safer to handle than chlorine. It produces fumes which are very irritating and the liquid causes severe burns. It is a good germicidal agent and effective tests are available for determining residual concentration. As with chlorine, the amine form is produced when ammonia is present, and the breakpoint phenomenon has been demonstrated. Bromine, hypobromous acid (HOBr), and monobromamine are considered nearly equal in bactericidal properties and essentially equal to free chlorine at comparable pH. Some of the advantages give for using bromine are: (a) it is easier to feed and not as hazardous to store as chlorine; and (b) the bactericidal efficiency of bromamines is much greater than that of chloramines. Data accumulated on an EPA sponsored Grant No. 17060 DNU by the Illinois Water Survey Laboratory indicate that the effectiveness of chlorine decreases with increasing pH, whereas bromine is most effective at high pH. This indicates potential for use with effluents subjected to phosphate removal with lime or ammonia stripping where the effluents have high pH. Possible potential for combing bromine and chlorine for disinfection was indicated. Cost-wise liquid bromine costs approximately 3.5 times more than chlorine.

Iodine

Commercial iodine is a nonmetallic solid. It is usually referred to as "metallic" iodine and has the appearance of dark, shiny, thin pieces of metal. In this form it is corrosive and ordinary metal containers are unsuitable for shipment or storage. It is dense and sublimes slowly at room temperatures. The hazards due to toxic vapors of iodine are less than the other halogens considered for disinfection of water or wastewater. The vapor pressure of iodine at 25o C is only 0.31 mm Hg. The corresponding figures for bromine and chlorine are 215 and 5,300 mm Hg respectively. Iodine is not considered to form iodamines under conditions prevailing in wastewater and organic demand may be less of a problem than with chlorine and bromine. Plant treatment of large volumes of wastewater with iodine would not ordinarily be economically feasible because it is significantly more expensive than chlorine, in terms of cost per unity of germicidal effectiveness. It primary potential may be for use in arctic fly-in outpost settlements where it can be shipped in light weight cardboard cartons. The cost of disinfecting with iodine is roughly 18 times more than the cost of an equivalent amount of chlorine. While some reduction in dosage with iodine might be considered becasue of probable increased persistence of the germicidal residual, the economics are strongly against the use of iodine as a substitute for chlorine except under circumstances where cost is a secondary consideration.

Ionizing Radiation

Ionizing radiation has been studied extensively as a potential sterilizing agent for foods. Its use as a disinfectant of wastewater effluents, either alone or in combination with another disinfectant, has been suggested in the literature. Its potential advantages include: (a) greater penetrating power than other forms of radiation, such as ultraviolet light; (b) no residual produced in the effluent stream; (c) capability of initiating oxidation of organic molecules and refractory pollutants.

The sources of high energy radiation are cobalt-60, cesium-137, electron accelerators, reactor loops, fuel elements, and mixed fission products. Each must be analyzed in terms of costs, availability, characteristics, and installation requirements. All radiation devices require special shielding and handling facilities, constant monitoring of radiation areas, keeping of personnel exposure records, etc. The electron accelerator facility requires electric power for operation. Due to the dearth of information relative to the practicality of any of these radiation sources, only rough cost estimates have been made. A recent study investigating the combined bactericidal effect of cobalt-60 gamma radiation and monochloramine on aqueous suspension of Escherichia coli indicates at most an additive effect. Thus, unless a significant synergistic effect can be demonstrated when radiation is used in combination with another disinfectant, radiation disinfection costs appear prohibitive for general wastewater treatment.

Low pH as a Disinfectant

Exposure of microoganisms to extremes in hydrogen ion concentration is a relatively ineffective method of disinfection. It is known that Escherichia coli can withstand a pH 1-2 environment for one hour with only a 75-80% loss in viability. Salmonella typhosa is somewhat more sensitive. A pH value of 4-5 is ineffective in reducing the viable count of these organisms. These statements are further substantiated when one considers that enteric bacteria must survive the extreme acid pH of the stomach before entering the small intestine. Thus, for low pH to be a truly effective disinfectant, extreme acidity must persist for a considerable period of time.

TABLE VIII

COST SUMMARY

PLANT SIZE, MGD	1	10	100
CAPTIAL COST	$K	$K	$K
PROCESS			
Chlorine	60	190	840
Chlorine/SO_2	70	220	930
Chlorine/SO_2/Aeration	120	360	1,580
Chlorine/Carbon	640	2,800	8,400
Ozone/Air*	190	1,070	6,880
Ozone/Oxygen*	160	700	4,210
Ultraviolet*	70	360	1,780
Bromine Chloride	50	130	410
Activated Sludge	1,450	5,790	39,800
DISINFECTION COST	¢/KGal.	¢/KGal.	¢/KGal.
PROCESS			
Chlorine	3.49	1.42	0.70
Chlorine/SO_2	4.37	1.75	0.89
Chlorine/SO_2/Aeration	7.66	2.39	1.19.
Chlorine/Carbon	19.00	8.60	3.28
Ozone/Air	7.31	4.02	2.84
Ozone/Oxygen*	7.15	3.49	2.36
Ultraviolet*	4.19	2.70	2.27
Bromine Chloride	4.52	3.04	2.65
Activated Sludge	55.90	20.20	14.00

* Tertiary treatment stage is not included in these costs.

TABLE IX

SUMMARY ON THE STATUS OF DISINFECTANTS

	State-of the-Art	Energy KWH/MG	Health Effects	Aquatic Toxic Effects
Chlorine	Operational	90	Assume Chlorinated Organics	High
Sodium Hypochlorite	Operational	280	Assume Chlorinated Organics	High
Chlorine/Sulfur Dioxide	Operational	90	Assume Chlorinated Organics	Low
Chlorine/Carbon	Pilot Plant	110	Assume Minimal	Low
Ozone/Air	Pilot Plant	800	Unknown	Low
Ozone/Oxygen	Pilot Plant	400	Unknown	Low
Ultraviolet	Pilot Plant	350	Assume Minimal	Assume Low
Bromine Chloride	Pilot Plant	90	Halogenated Organics	Intermediate

APPENDIX A - RESEARCH AND DEVELOPMENT PROJECTS

Listed below are brief descriptions of EPA research projects on disinfection.

I. On Going Projects

A. "Parallel Ozonation and Chlorination with Dechlorination of Chlorinated Effluent." Project No. 802292, City of Wyoming.

A study on disinfection effectivenss and bioassay effects of chlorine, ozone, dechlorination with suflur dioxide and bromine chloride. Estimated completion date, Jan. 1976.

B. "Ultraviolet Disinfection of Municipal Effluents", Project No. 803292, City of Dallas.

The evaluation of ultraviolet light as a disinfectant for wastewater.

C. "Reduction of Toxicity Emission Rates from Wastewater Treatment Plants by Optimization of the Chlorination Process." Project No. 803459, State of California.

Develop cost effective design parameters for the chlorination process.

D. "Multicell Lagoons - Micro Organism Removal Efficiency and Effluent Disinfection", Project No. 803294, Utah State University.

Define the lagoon equivalency to disinfection and determine whether chlorination will affect the organic content of effluent.

E. "A Comparative Study of the Inactivation of Viruses in Waste, Renovated and Other Waters by Chlorine and Chlorine Compounds". Project No. 800370, University of Cincinnati.

Determine the capability of chlorine and chlorinated compounds to destroy viruses in wastewaters.

F. "New Microbial Indicators of Wastewater Chlorination Efficiency", Project No. 800712, University of Illinois.

Develop a biological indicator that is more suitable and reliable than the coliform group. Report No. EPA 670/2-73-082.

G. "Ozone Contactor Study", AWTRL Pilot Plant,

An evaluation of ozone contactor efficiencies.

II. Completed Projects

A. "The Detection and Inactivation of Enteric Viruses in Wastewater", Project No. 800990, Hebrew University.

Develop effective and economical procedures for the inactivation of viruses in wastewater by ozone.

B. "Batch Disinfection of Treated Wastewater with Chlorine at Less Than 1 C," Project 16100 GKG, Arctic Environmental Research Laboratory, Report No. EPA-660/2-73-005.

C. "Lime Disinfection of Sewage Bacteria at Low Temperature", Project 16100 PAK, Colorado State University, Report No. EPA-660/73-017.

D. "Hypochlorite Generator for Treatment of Combined Sewer Overflows", Report No. 110233 DAA 03/72, Ionics Incorporated.

E. "Ultraviolet Disinfection of Activated Sludge Effluent Discharging to Shellfish Waters", Project No. WPRD 139-01-68, The Town of St. Michaels.

F. "Disinfection of Sewage Effluents", Project No. 17060 DNV University of Illinois, Bromine and Chlorine Disinfection Results.

G. "Demonstrate Effectiveness of Iodine for the Disinfection of Public Water Supplies", Project No. 19-06-68, City of Gainesville.

H. "Hypochlorination of Polluted Stormwater Pumpage at New Orleans", Report No. EPA-670/2-73-067, Pavia-Byrne Engineering Corporation, New Orleans, La.

I. "Bench-Scale High-Rate Disinfection of Combined Sewer Overflows with Chlorine and Chlorine Dioxide", Project No. 802400, O'Brien and Gere Engineers, Inc. Syracuse, New York.

APPENDIX B - STATE STANDARDS (EXISTING)

A. Water Quality

- Coliform limitations based on stream use of basin designation: all States except Nevada.
- Seasonally or hydrographically based: 9 States.
- General toxicity standard applied thru permits: 9 States.
- Maximum chlorine residual standard applied thru permits: 6 States.
- State maximum chlorine residual limitations: 3 States.

B. Disinfection

- Year-round disinfection: 21 States.
- Universal disinfection with case-by-case exception: 1 State.
- Case-by-case disinfection requirements: 19 States.
- No specific requirements: 1 State.
- Secondary treatment - no specific disinfection requirement: 19 States.
- No standards: 8 States.
- Minimum chlorine residual: 5 States.

APPENDIX C

TABLE I. Tentative Indentification and Concentrations of Chlorine-Containing Constituents in Chlorinated Effluents

Identification	Concentration of Organic Compound (ug/liter)
5-Chlorouracil	4.3
5-Chlorouridine	1.7
8-Chlorocaffeine	1.7
6-Chloroguanine	0.9
8-Chloroxanthine	1.5
2-Chlorobenzoic acid	0.26
5-Chlorosalicylic acid	0.24
4-Chloromadnelic acid	1.1
2-Chlorophenol	1.7
4-Chlorophenylacetic acid	0.38
4-Chlorobenzoic acid	1.1
4-Chlorophenol	0.69
3-Chlorobenzoic acid	0.62
3-Chlorphenol	0.51
4-Chlororesorcinol	1.2
3-Chloro-4-hydroxy-benzoic acid	1.3
4-Chloro-3-methyl-phenol	1.5

TABLE II. Organochlorine Compounds in Water from Sewage Treatment Plants

Compound[a]	Concentration (ug/l) Influent before Treatment	Effluent before Chlorination	Effluent after Chlorination
Methylene chloride	8.2	2.9	3.4
Chloroform	9.3	7.1	12.1
1,1,1-Trichloroethane	16.5	9.0	8.5
1,1,2-Trichloroethylene	40.4	8.6	9.8
1,1,2,2-Tetrachloroethylene	6.2	3.9	4.2
Dichlorobenzenes	10.6	5.6	6.3
Trichlorobenzenes	66.9	56.7	56.9

[a]All confirmed by GC-MS

TABLE III. Trihalogenated Methane Content of Water from Water Treatment Plant

Sample Source	Sampling Point	Free Chlorine ppm	Concentration (ug/l) Chloroform	Bromodichloromethane	Dibromochloromethane
Raw river water	1	0.0	0.9	a	a
River water treated with chlorine and alum-chlorine contact time 80 min.	2	6	22.1	6.3	0.7
3-day-old settled water	3	2	60.8	18.0	1.1
Water flowing from settled areas to filters[b]	4	2.2	127	21.9	2.4
Filter effluent	5	Unknown	83.9	18.0	1.7
Finished water	6	1.75	94.0	20.8	2.0

[a]None detected. If present, the concentration is less than 0.1 ug/l.

[b]Carbon slurry added at this point.

TABLE IV

SOME RECOGNIZED AND SUSPECT CARCINOGENS FOUND
IN MUNICIPAL WATER SUPPLIES

CHEMICAL	ASSOCIATED WATERWAY
Bis (2-Chloroethyl) Ether	Ohio River
Chlorodibromomethane	Ohio River
Bromoform	Ohio River
Benzene	Ohio River and Wabash River
Carbon Tetrachloride[R]	Ohio River
Bis Chloromethyl Ether[R*]	Ohio River
Chloromethyl Methyl Ether[R]	Ohio River
Choromethyl Ethyl Ether	Ohio River

R = recognized carcinogen
* = decomposes readily

TABLE V. Halo-organic Compounds Identified in Drinking Waters in the United States (as of 11/25/74)

1. acetylene dichloride
2. aldrin
3. atrazine
4. (deethyl) atrazine
5. bromobenzene
6. bromochlorobenzene
7. bromodichloromethane
8. bromoform
9. bromoform butanal
10. bromophenyl phenyl ether
11. carbon tetrachloride
12. chlordan (e)
13. chlorobenzene
14. chlorodibromomethane
15. 1,2-bis-chloroethoxy ethane
16. chloroethoxy ether
17. bis-2-chloroethyl ether
18. b-chloroethyl methyl ether
19. chloroform
20. chlorohydroxy benzophenone
21. bis-chloroisopropyl ether
22. chloromethyl ether
23. chloromethyl ethyl ether
24. m-chloronitrobenzene
25. 3-chloropyridine
26. DDE
27. DDT
28. dibromobenzene
29. dibromochloromethane
30. dibromodichloroethane
31. 1,4-dichlorobenzene
32. dichlorodifluoroethane
33. 1,2-dichlorobenzene
34. dichloroethyl ether
35. dichloromethane
36. dieldrin
37. heptachlor
38. heptachlor epoxide
39. 1,2,3,4,5,6,7,7-heptachloronorbornene
40. hexachlorobenzene
41. hexachloro-1,3-butadiene
42. hexachlorocyclohexane
43. hexachloroethane

TABLE V (cont.)

44. methyl chloride
45. octyl chloride
46. pentachlorobiphenyl
47. pentachlorophenol
48. 1,1,3,3-tetrachloroacetone
49. tetrachlorobiphenyl
50. tetrachloroethane
51. tetrachloroethylene
52. trichlorobenzene
53. trichlorobiphenyl
54. 1,1,2-trichloroethane
55. 1,1,2-trichloroethylene
56. trichlorofluoromethane
57. 2,4,6-trichlorophenol

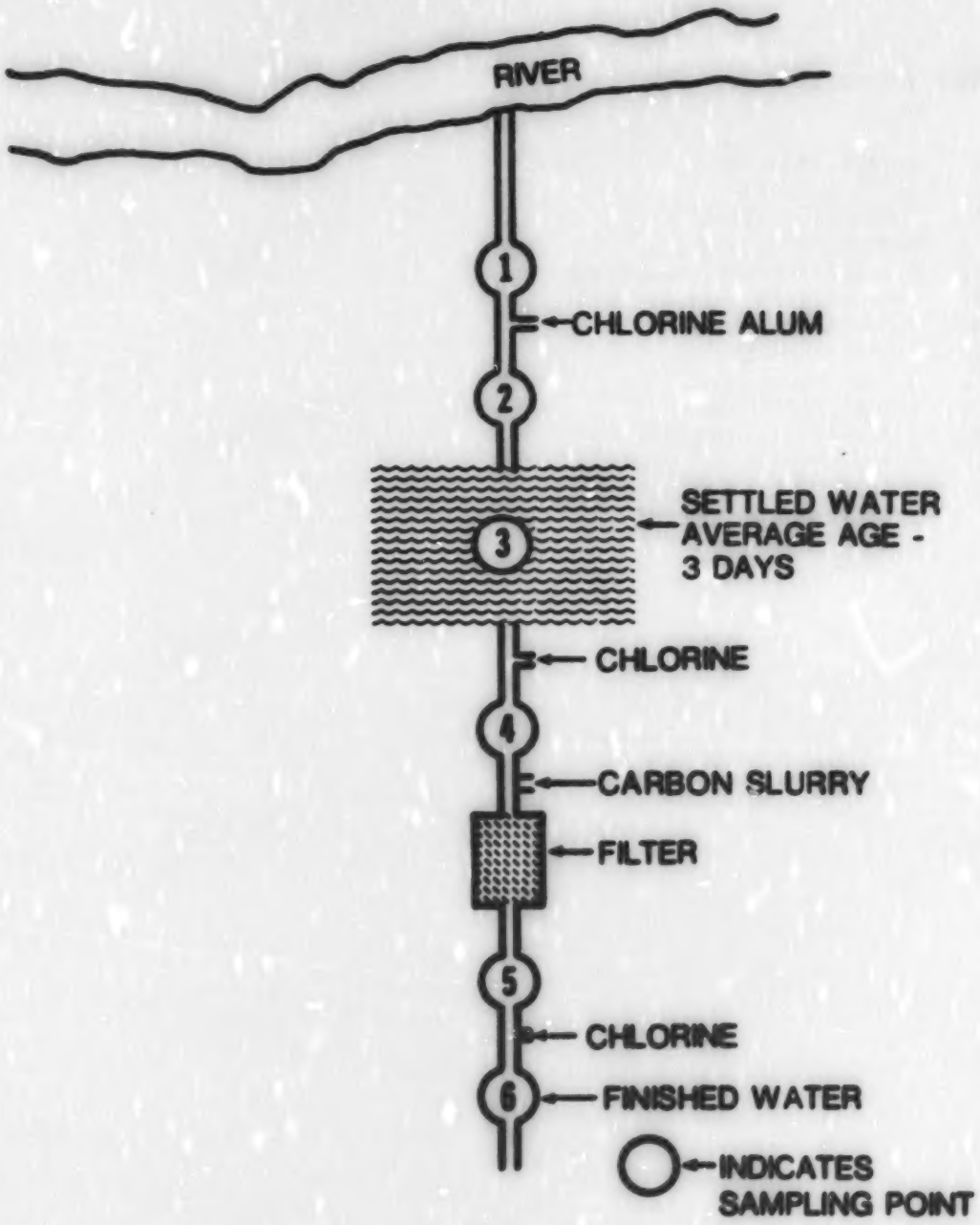

Figure 1. WATER TREATMENT PLANT SAMPLING POINTS

APPENDIX D

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